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Age Effects in Identifying and Localising Dichotic Stimuli: A Corpus Callosum Deficit?*

Liselotte Gootjes[1], Jan W. Van Strien[2], and Anke Bouma[3]
[1]Department of Clinical Neuropsychology, Vrije Universiteit, Amsterdam, The Netherlands,
[2]Institute of Psychology, Erasmus University, Rotterdam, The Netherlands,
and [3]Department of Developmental and Clinical Neuropsychology, Rijksuniversiteit Groningen, The Netherlands

ABSTRACT

In the present study, dichotic listening performance of 31 older adults was compared with performance of 25 younger adults under free and focussed attention conditions. In addition to an age-related general decrease in performance, we observed in the focussed attention condition increased asymmetry in the elderly group: the decrease of recall performance was stronger for the left ear (LE) than for the right ear (RE), while the increase of localisation errors was greater for the RE than for the LE. Identifying and localising digits appear to be different processes mediated predominantly by the left and right hemisphere, respectively. Since age-related reduced performance is strongest for the ear ipsilateral to the hemisphere dominant to that particular function, these findings may be ascribed to decline of corpus callosum functioning resulting in decreased interhemispheric interaction rather than to a selective decline of right hemisphere functions.

Age-related decline in cognitive functioning in healthy older adults appears to be restricted to tasks that demand more effortful processing. On tasks demanding automatic processing, elderly adults perform similarly to younger adults. Age-related decline most probably is a consequence of deficits in selective attention needed during effortful processing (Kinsbourne, 1980). In the present research, we studied age differences in dichotic listening performance. The dichotic listening test (DLT) is an excellent tool for examining age-related cognitive decline since it involves different degrees of attentional and memory processing.

The DLT is a non-invasive procedure to study the lateralisation of cerebral functions. Kimura (1961) developed the standard DLT, in which pairs of spoken digits are presented through a headphone. In each trial, three digits are sequentially presented to the left ear (LE), while at the same time three other digits are sequentially presented to the right ear (RE). The participants are asked to report as many digits as possible after each trial. Kimura (1967) found that verbal stimuli presented to the RE are reported more accurately than verbal stimuli presented to the LE.

According to the structural model proposed by Kimura (1967), this right-ear advantage (REA) is a consequence of the functional anatomical organisation of the central-auditory system and the cerebral representation of language functions. Although auditory information is processed in the

*Performed at the Department of Clinical Neuropsychology, Vrije Universiteit, Amsterdam, The Netherlands.
Address correspondence to: Liselotte Gootjes, Department of Clinical Neuropsychology, Vrije Universiteit, Van der Boechorststraat 1, 1081 BT Amsterdam, The Netherlands. Tel.: +31-20-4448954 or +31-20-4448756. Fax: +31-20-4448971. E-mail: L.Gootjes@psy.vu.nl or J.M.Bouma@ppsw.rug.nl

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brain along ipsilateral and contralateral pathways, it has been postulated that the contralateral projections are stronger, more numerous and more rapidly conducting. Additionally, it has been suggested that during dichotic stimulation the information along the ipsilateral pathways is suppressed by the information from the contralateral pathways (Kimura, 1967). In the great majority of individuals, the left hemisphere is dominant for language functions. Thus, information from the RE, which reaches the dominant left hemisphere directly, would be processed faster and more accurately than information from the LE that has to be transferred across the corpus callosum to reach the language-dominant left hemisphere, thus inducing a REA.

Although the standard DLT requires participants to divide their attention between both ears, participants are free to adopt attentional strategies such as directing most of the attention to one ear, which is then reported first. In order to control volitional attention shifts of the participant, focussed attention instructions have been introduced (Bryden, 1971; Bryden, Munhall, & Allard, 1983). In simple focussed attention paradigms, the participant is instructed to focus attention on one ear selectively and to recall the stimuli from the attended ear only (one-ear report). In more complex paradigms, the participant is asked to recall the stimuli from one ear first and from the other ear second (two-ear report), and visa versa. In that case, the participant has to direct most of the attention to a designated ear but at the same time take notice of the other ear. This latter paradigm allows study of the performance of both the 'attended' ear, which receives most of the attention, and the 'unattended' ear, which receives less attention. The stimuli from the attended ear have to be reported immediately, thus performance of this ear relies strongly on immediate perception. On the other hand, the performance of the unattended ear relies strongly on short-term memory function since the stimuli from this ear have to be kept in memory while the information from the other ear is being reported.

Given the attentional and memory components of the DLT, significant age effects on dichotic listening performance can be expected. Indeed, research has demonstrated that the DLT performance of elderly is decreased compared to younger participants (Alden, Harrison, Snyder, & Everhart, 1997; Bouma & Van der Endt, 1993; Gelfand, Hoffman, Waltzman, & Piper, 1980; Hallgren, Larsby, Lyxell, & Arlinger, 2001; Martin & Cranford, 1991; Strouse, Wilson, & Brush, 2000a). Also, an age-related increase of ear asymmetry has been reported: performance of the LE has been found to decrease stronger than performance of the RE (Jerger, Alford, Lew, Rivera, & Chmiel, 1995; Jerger, Chmiel, Allen, & Wilson, 1994; Strouse et al., 2000a; Strouse, Wilson, & Brush, 2000b). However, this finding is still controversial since some aging studies have failed to find such an effect (Gelfand et al., 1980; Martini et al., 1988) or found that age effects could only be perceived in focussed attention conditions, in particular when attention had to be focussed at the LE (Alden et al., 1997; Bouma & Van der Endt, 1993; Hallgren et al., 2001). Findings of decreased LE performance in elderly suggest that aging differentially affects functional hemispheric asymmetry.

The present study deals with dichotic listening performance of older adults compared to the performance of younger adults under free and focussed attention conditions. By examining serial position effects, we want to investigate age effects in dichotic listening at a more qualitative level. In the standard DLT, dichotic stimuli are presented sequentially. The processing of such sequentially presented stimuli is strongly influenced by memory functions that are known to be diminished in elderly (Kinsbourne, 1980). In this view it would be interesting to examine whether an age-related decrease of performance depends on the serial position of a stimulus within a trial. It may be hypothesised that the first presented stimuli are most prone to age effects since reporting of the first presented stimuli depends strongly on memory processing.

In addition to serial position effects, we examine localisation errors. Although focussed attention instructions are given primarily to control spatial orientation effects, at the same time such instructions introduce an additional spatial aspect. The participant not only has to recall which digits have been heard (i.e. the participant has to identify the stimuli), but also in which ear the digits were heard (i.e. the participant has to localise the stimuli). Considering the age-related decrease in recall performance found in previous studies on dichotic listening, it could be expected that elderly have more difficulties in localising dichotic stimuli as well. Furthermore, it has been suggested that asymmetry in localisation errors is directly related to a right ear advantage (Bryden et al., 1983). From this point of view it can be hypothesised that if the right ear advantage increases with age, asymmetry in localisation errors might also increase with age. Whether a possible asymmetry in localisation errors is related to age will be explored in this study as well.

METHODS

Participants

Twenty-five undergraduate students (13 women, 12 men) with ages ranging from 19 to 29 years (mean age $\pm$ *SD* was 23.0 ± 2.8 years) were recruited from the *Vrije Universiteit* in Amsterdam and 31 elderly (15 women, 16 men) with ages ranging from 61 to 80 years (mean age $\pm$ *SD* was 69.8 ± 5.7 years) were recruited from the pensioners society of the *Vrije Universiteit* in Amsterdam. All were native Dutch speakers and were paid for their participation. Hand preference was evaluated with a 10-item Dutch handedness questionnaire (Van Strien, 1992). All participants had a minimum score of $+9$ on a scale ranging from -10 (strongly left-handed) to $+10$ (strongly right-handed). Auditory screening was used to examine hearing threshold at 1000, 1500, 2000, 3000 and 4000 Hz and revealed normal hearing in all young participants and age-related bilaterally symmetrical decrease of hearing in the elderly participants. Individuals with more than 6 dB difference between mean hearing thresholds of the RE and LE were excluded from participation. In addition, individuals with more than 15 dB difference between ears for hearing thresholds at 1000, 1500, 2000 and 3000 Hz or with more than 20 dB difference between ears for hearing thresholds at 4000 Hz were excluded from participation. Participants reported no presence of hearing problems, speech therapy, neurological disorders or psychiatric disorders. Auditory dichotic stimuli were presented at a mean sound pressure level of 85 dB. All participants were explicitly asked whether this level was audible and comfortable.

Materials

Ten monosyllabic Dutch digits (1–6, 8, and 10–12) were spoken by a female voice and were digitally recorded. The duration of each digit was digitally equated to 450 ms. Digits were arranged in pairs in such a way that two consecutive digits in a pair were not allowed. The two paired digits were presented simultaneously: one at the RE and one at the LE. Each trial consisted of three pairs (six different digits) in sequence in such manner that two consecutive digits were not allowed to follow after each other in one ear. The interval between pairs within a trial was 50 ms and the inter-trial interval was 9.5 s. All digit combinations were counterbalanced between the two channels within the test trials of each condition. In the focussed attention conditions, each trial was preceded by a 550 ms 400 Hz tone and a 900 ms silence interval. The tone was presented either to the LE in the LE-focussed attention condition or to the RE in the RE-focussed attention condition. Trials were presented through earphones (ME 70 noise-excluding headset fitted with TDH 39 receivers, Madsen Electronics, Copenhagen) at a mean sound pressure level of 85 dB.

Procedure

Each participant was tested individually in a quiet room. The entire procedure was completed in one session. After the auditory screening, the participant first completed the handedness questionnaire and a personal medical history questionnaire. The DLT consisted of three conditions: a free attention condition, a focussed attention condition in which attention had to be focussed to the LE and a focussed attention condition in which attention had to be focussed to the RE. Each condition was composed of two warm-up trials and 20 test trials. All participants started with the free attention condition followed by the focussed attention conditions. Within the focussed attention condition, the order of the attention to the LE condition and the attention to the RE condition was counterbalanced across age and gender group. In the free attention condition, the participants had to recall as many digits as possible, irrespective of the ear in which the digits were heard. In the focussed attention condition, they had to recall first as many digits as possible from the ear in which the tone was presented and then as many digits as possible from the other ear. Participants had to indicate verbally when they switched reporting digits from the attended ear to reporting digits form the unattended ear. A short practice session of five trials was done prior to each condition to make sure the participants understood the instructions and felt comfortable with the task.

Scoring

For each ear (LE or RE) and position (first, second, or third position), the total number of correctly recalled digits was determined. For the focussed attention conditions, additionally, a localisation error score was determined for each position, ear and condition. For instance, a localisation error for the unattended RE means that the participant correctly identified a digit presented to the unattended RE, but incorrectly indicated that this digit was presented at the attended LE. To calculate the localisation score, the number of digits that were recalled correctly but attributed to the wrong ear, were divided by the total number of correctly recalled digits for that ear at that position.

Data Analysis

Analyses of variance (ANOVAs) with repeated measures were performed separately for the free and focussed attention conditions. Analyses of data of the free attention condition were done with Ear (LE and RE) and Position (1st, 2nd, and 3rd position) as within-subject variables and Age (Young and Old) as between-subject variable. Analyses of data of the focussed attention conditions involved an additional within-subject variable, namely Attention (attended and unattended ear). Position effects were further analysed with post hoc contrast analyses. Since preliminary ANOVAs with gender as a between-subject variable did not result in any significant effects for this factor, data for subsequent analyses were collapsed across men and women. For illustrative reasons, mean percentages correct responses are depicted in the figures, although statistical analyses were performed with absolute scores.

RESULTS

Free Attention

The mean recall scores as a function of age, ear, and position are displayed in Table 1. The ANOVA yielded significant main effects for Ear, $F(1, 54) = 30.60$, $p < .001$, reflecting better recall performance for the RE, and for Age, $F(1, 54) = 22.40$, $p < .001$, reflecting decreased recall performance of the elderly. A main effect for Position, $F(2, 108) = 28.83$, $p < .001$, showed that digits at the first and third position are recalled more accurately than digits at the second position (post hoc contrasts: $F(1, 54) = 7.49$, $p < .01$ and $F(1, 54) = 71.69$, $p < .001$, respectively). No significant interactions were found.

Focussed Attention – Recall Performance

The mean recall scores as a function of age, attention, ear, and position are displayed in Table 2. Analyses revealed a significant main effect for Ear, $F(1, 54) = 45.32$, $p < .001$, reflecting a REA, and for Attention, $F(1, 54) = 238.73$, $p < .001$, reflecting increased recall performance of the attended ear. Also a significant Ear $\times$ Attention interaction, $F(1, 54) = 7.4$, $p < .01$, was found, indicating that the REA is greater for the unattended than for the attended ear. A significant interaction for Ear $\times$ Attention $\times$ Position, $F(2, 108) = 8.42$, $p < .001$, indicated that the serial position effects are stronger for the unattended than for the attended ears. In addition to a significant main effect for Age, $F(1, 54) = 22.23$, $p < .001$, reflecting decreased recall performance of the elderly, a significant Ear $\times$ Age interaction was found, $F(1, 54) = 6.34$, $p < .05$. In the elderly the decline is stronger for the LE than for the RE, resulting in an increased overall REA (Fig. 1A). Additionally, a significant Attention $\times$ Age interaction, $F(1, 54) = 9.94$, $p < .01$, indicated that the decline in the elderly is stronger for the unattended than for the attended ears (Fig. 1B). In addition to a significant main effect for Position, $F(2, 108) = 92.57$, $p < .001$, a significant Position $\times$ Age interaction, $F(2, 108) = 5.74$, $p < .01$, showed that the position effect depends on age. In the young group, digits at the first and third position are recalled more accurately than digits at the second position (post

Table 1. Mean Accuracy Scores in the Free Attention Condition as a Function of Age, Ear and Position.

	Left				Right			
	1	2	3	Total	1	2	3	Total
Younger	14.9	13.7	16.6	15.1	18.3	16.2	18.0	17.5
Older	11.9	11.1	13.5	12.2	15.8	14.1	16.6	15.5
Total	13.4	12.4	15.0	13.6	17.0	15.2	17.3	16.5

Table 2. Mean Accuracy Scores in the Focussed Attention Condition as a Function of Age, Attention, Ear and Position.

	Left				Right			
	1	2	3	Total	1	2	3	Total
Younger								
Attended	19.0	18.9	19.0	19.0	19.8	19.4	19.5	19.6
Unattended	13.0	11.8	17.5	14.1	15.0	13.0	17.5	15.1
Older								
Attended	17.6	17.5	18.4	17.8	19.1	19.2	19.0	19.1
Unattended	7.5	7.5	15.6	10.2	11.5	10.5	15.8	12.6
Total								
Attended	18.3	18.2	18.7	18.4	19.5	19.3	19.3	19.3
Unattended	10.2	9.6	16.6	12.1	13.3	11.7	16.7	13.9

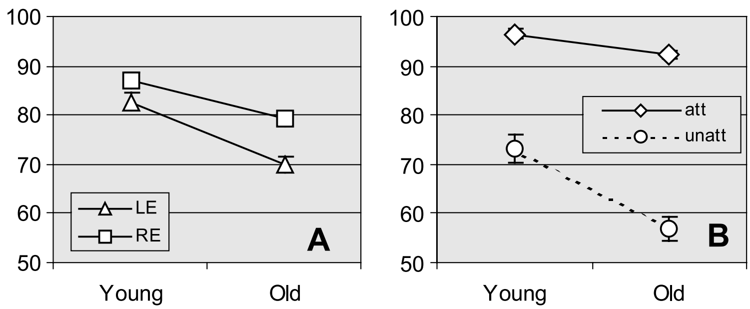

Fig. 1. Mean percentage correct (error bars indicate *SEM*) as a function of ear and age (A) and attention and age (B) in the focussed attention condition.

hoc contrasts: $F(1,24) = 9.70$, $p < .005$, $p < .005$ and $F(1,24) = 82.38$, $p < .001$, $p < .001$, respectively), while in the elderly only digits at the third position are recalled more accurately than digits at the second position (post hoc contrast: $F(1,30) = 96.35$, $p < .001$) (Fig. 2).

Focussed Attention – Localisation Errors

The mean localisation errors as a function of age, attention, ear, and position are displayed in Table 3. The ANOVA yielded a significant main effect for Ear, $F(1,54) = 13.51$, $p < .001$, indicating more localisation errors for the RE, and for Attention, $F(1,54) = 48.50$, $p < .001$, indicating more localisation errors for the unattended ear, and a significant Ear × Attention interaction, $F(1,54) = 14.00$, $p < .001$. The increase of localisation errors was stronger for the unattended RE than for the unattended LE. In addition to a

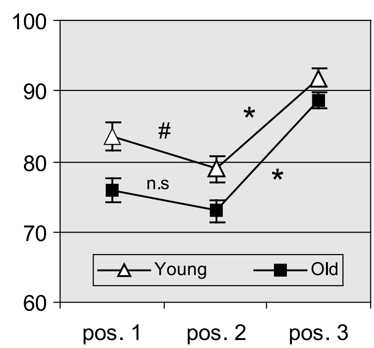

Fig. 2. Mean percentage correct (error bars indicate *SEM*) as a function of age and position in the focussed attention condition. $^*p < .001$; $^{\#}p < .005$; *ns* $p =$ not significant.

significant main effect for Age, $F(1,54) = 4.81$, $p < .05$, indicating more localisation errors in the elderly group, an Ear × Age interaction,

Table 3. Mean Proportion Localisation Errors in the Focussed Attention Condition as a Function of Age, Attention, Ear and Position.

	Left				Right			
	1	2	3	Total	1	2	3	Total
Younger								
Attended	3.8	4.0	6.6	4.8	3.0	2.7	3.8	3.2
Unattended	9.4	7.5	5.7	7.5	15.0	12.1	6.6	11.2
Older								
Attended	3.3	2.0	5.2	3.5	2.4	2.0	1.8	2.1
Unattended	21.7	17.1	5.4	14.7	33.9	26.9	11.4	24.1
Total								
Attended	3.6	3.0	5.9	4.2	2.7	2.4	2.8	2.6
Unattended	15.5	12.2	5.6	11.1	24.5	19.5	9.0	17.7

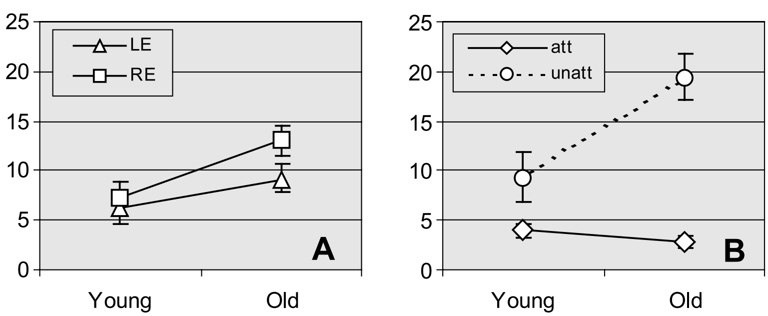

Fig. 3. Mean proportion localisation errors (bars indicate *SEM*) as a function of ear and age (A) and attention and age (B) in the focussed attention condition.

$F(1,54) = 4.63$, $p < .05$, indicated that in the elderly group increase of localisation errors was stronger for the RE than for the LE (Fig. 3A). Also, a Attention $\times$ Age interaction $F(1,54) = 12.63$, $p < .001$, was found. The difference between the localisation errors in the attended and unattended ear was larger for the elderly than for the young group (Fig. 3B). There was a significant main effect for Position, $F(2,108) = 12.18$, $p < .001$, a significant Age $\times$ Position interaction, $F(2,108) = 5.02$, $p < .01$, a significant Attention $\times$ Position interaction, $F(2,108) = 16.3$, $p < .001$, and a significant Attention $\times$ Age $\times$ Position interaction, $F(2,108) = 3.2$, $p < .05$. The attention effects are greatest at the first position and smallest at the last position and

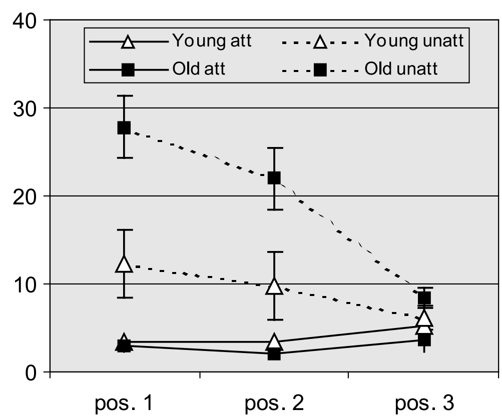

Fig. 4. Mean proportion localisation errors (error bars indicate *SEM*) as a function of age, attention and position in the focussed attention condition.

there is a difference in localisation errors in the unattended ear between the young and older group at the first and second position (Fig. 4).

DISCUSSION

In the present study, we compared dichotic listening performance of older adults with performance of younger adults. We found an age-related overall decrease in performance, reflected by a decrease in recall performance and an increase in localisation errors in the elderly group. Interestingly, in contrast to the free attention condition, we found in the focused attention condition increased asymmetry in the elderly group: recall performance was more strongly decreased for the LE than for the RE whereas the increase of localisation errors was greater for the RE than for the LE. Age effects were found to be affected by serial position: age effects were strongest for digits at the first position and weakest for digits at the third position.

Reduced Recall Performance in Elderly

Compared to the younger adults, older adults showed reduced recall performance in both the free and focussed attention condition. This is in agreement with earlier studies that have shown decreased performance in elderly (Alden et al., 1997; Hallgren et al., 2001; Strouse et al., 2000a, 2000b). Analyses of serial position effects show that age effects are strongest for the digits at the first position. Although recall performance of both groups seems to show the classical U shape serial position curve (Fig. 2), only in the younger group, but not in the older group, recall performance of the first presented digit was significantly increased compared to the second presented digit. Conversely, both groups showed increased recall performance of the last presented digit compared to the second presented digit, pointing at some sort of recency effect. A generally accepted interpretation of serial position effects in free recall is that primacy reflects active rehearsal of the first items in a list (Rundus, 1971) while recency effects are suggested to reflect semi-automatic output of the most recent items from a short-term phonological buffer (e.g. Koppenaal & Glazner, 1990). Recency effects would involve passive, automatic processes that require little attention while primacy involves more or less active controlled or effortful processes (Hasher & Zacks, 1979). In this view, the finding of reduced primacy effects and unchanged recency effects in our elderly group indicated that intentional control is diminished in the elderly while the automatic processing of the stimuli is still intact.

Furthermore, age-effects in recall performance are found to be strongest for the unattended ear (Fig. 1B). Since successful performance of the unattended ear puts stronger demands on cognitive processes like memory than successful performance of the attended ear, strong age-effects for the unattended ear might be due to decreased memory in elderly. As a matter of fact, in elderly a strong connection between age-related cognitive decline and reduced performance in dichotic listening has been found (Hallgren et al., 2001). Age-effects in dichotic listening become stronger with paradigms involving increased demands on memory (Strouse et al., 2000a, 2000b).

Increased Localisation Errors in the Elderly

Increased localisation errors in the elderly group indicates that this group had more difficulties in localising digits to the correct ear. Since this increase can be attributed solely to increase of localisation errors for the unattended ear (Fig. 3B), it might be suggested that decreased cognitive functions like memory are also involved in age-related increase of localisation errors.

In both the younger group and the older group, localising digits is strongly influenced by attention: more localisation errors are made for the unattended ear than for the attended ear. This might be due to a tendency of the participant to attribute targets to the attended ear irrespective of the actual ear of presentation. Indeed, it has been found that shifting attention to one ear selectively results in a response bias such that stimuli are more often attributed to the attended ear than to the unattended ear (Hiscock, Inch, & Kinsbourne, 1999a, 1999b). In this view, elderly might have an increased response bias to attribute digits to the attended ear that might be due to difficulties in intentionally controlling attention. Also, the presence of serial position effects in age-related increase of localisation errors points at a strong influence of decreased memory functions in elderly. Age-related increase was only present in the unattended ear for the first and second presented digits, but not for the last presented digits (Fig. 4). Performance of the first presented digits that relies more strongly on memory processes, seems to suffer more strongly from ageing than performance of the last presented digits that relies more strongly on immediate perception.

Increased Asymmetry in Recall Performance in Elderly

Both the younger group and the older group showed a REA for recall performance that can be interpreted as increased involvement of the left hemisphere in recalling dichotic presented digits. Digits presented to the RE were recalled more accurately than digits presented to the LE. Moreover, this ear asymmetry was increased in the elderly in the focussed attention condition, that is, recall of the LE declined more strongly than recall of the RE (Fig. 1A). Several studies also found an age-related decrease of LE performance (Alden et al., 1997; Bellis & Wilber, 2001; Bouma & Van der Endt, 1993; Hallgren et al., 2001; Jerger et al., 1994, 1995; Strouse et al., 2000a, 2000b).

To explain this increased ear asymmetry in elderly, several theories have been proposed. The hemi-aging (Lapidot, 1983) or right-hemisphere dysfunction hypothesis (Goldstein & Shelly, 1981) proposes that the functions of the right hemisphere decline faster with age than the functions of the left hemisphere. Therefore, the LE would be more susceptible for age-related decrease in dichotic listening performance. The corpus callosum deficit theory (Goldstein & Braun, 1974) proposes that age-related decrease of corpus callosum size causes less efficient transmission of the information from the LE to the language-dominant left hemisphere and thereby results in decreased LE performance in elderly. Indeed, callosal size has been found to decrease with age (Doraiswamy et al., 1991; Sullivan et al., 2001; Weis, Jellinger, & Wenger, 1991) and to correlate with performance on dichotic listening tasks in healthy participants (Clarke, Lufkin, & Zaidel, 1993; O'Kusky et al., 1988; Yazgan, Wexler, Kinsbourne, Peterson, & Leckman, 1995) and in patients suffering from neurodegenerative diseases affecting white matter like multiple sclerosis (Gadea et al., 2002; Reinvang, Bakke, Hugdahl, Karlsen, & Sundet, 1994).

The absence of an age-related decrease of LE performance in the free attention condition might be due to the extent in which control of attention is needed. Dichotic listening tasks involving specific attention instructions require more extensive intentional processes and might therefore engage increased functioning of the frontal areas compared to tasks without such instructions. Indeed, fMRI research had demonstrated that dichotic listening involves activation not only of temporal areas but also of frontal areas (Jancke & Shah, 2002). Further, it has been found that the frontal lobes in particular are most susceptible to age-related brain changes (Coffey et al., 1992; Cowell et al., 1994). Age-related asymmetry might therefore be stronger in dichotic listening tasks involving increased control of attention processes as is the case in our focussed attention conditions. In the focussed attention conditions in the present study, the participant has to focus attention to one ear while taking notice of the other ear as well. This requires increased intentional control of attention compared to the free attention condition in which digits have to be recalled irrespective of the ear of presentation. In this view, age-related decrease of LE performance can be hypothesised to be due to a relative inability of the elderly group to intentionally shift attention to the LE. A natural preference to focus to the RE would be more difficult to overcome with increasing age. Actually, also some other studies found an age effect in the LE focussing condition but not in the RE focussing condition (Alden et al., 1997; Bouma & Van der Endt, 1993; Hallgren et al., 2001).

Ear Asymmetry in Localisation Errors

In both the younger group and the older group, we found ear asymmetry for localising stimuli for the unattended ears, showing better performance of the LE, that is, more localisation errors were made for the unattended RE than for the unattended LE. Bryden et al. (1983) hypothesised that increased localisation errors for the RE might be a direct effect of the REA and thus indicates a left hemisphere dominance. Localising digits might be easier when attending to the RE since the difference in strength between digits presented to the attended RE and the unattended LE might be greater than the difference in strength between digits presented to the attended LE and the unattended RE (Bryden et al., 1983). Thus, more localisation errors are made when attending to the LE than when attending to the RE. Since it is the unattended ear, that is most sensitive to localisation errors, ear asymmetry is most likely to be found for the unattended ears reflecting increased localisation errors for the unattended RE. Bryden's hypothesis implicates that less localisation errors would be made when the difference in strength between digits presented to the attended and the unattended ear increases. However, this is in contrast to our findings. In the elderly group, the difference in recall performance of the attended and unattended ear is increased compared to the younger group (Fig. 1B) which indicates that the difference in strength between digits presented to the attended and the unattended ear is increased. Nevertheless, we found increased localisation errors in the elderly group.

It can be argued that increased localisation errors for the unattended RE might simply be due to the fact that more digits were recalled for this ear which makes it more likely that these digits are attributed to the wrong ear. However, our score for localisation errors is determined by the proportion of digits that are recalled accurately for that ear but assigned to the wrong ear, and thus corrects for the number of digits that are recalled for each ear.

An alternative explanation of increased localisation errors for the unattended RE might be that better performance of the LE points at increased involvement of the right hemisphere in localising digits. Since ear asymmetry for localising digits is in the opposite direction of the asymmetry in identifying digits, it seems that identifying and localising auditory stimuli are distinct processes that are differentially lateralised. Indeed, it has been hypothesised that separate functional pathways exist for identifying the features of sound stimuli and for localising their spatial position (Rauschecker & Tian, 2000). Moreover, a right-hemisphere predominance for localising auditory stimuli is also consistent with brain imaging studies (Weeks et al., 1999; Zatorre, Bouffard, Ahad, & Belin, 2002). The absence of ear asymmetry for localising digits for the attended ears might indicate that such a right-hemisphere predominance for localising auditory stimuli is more likely to results in asymmetric behaviour when increased cognitive demands (e.g. increased memory load) are involved.

Increased Ear Asymmetry in Localisation Errors in Elderly

Compared to the younger group, the elderly group showed increased ear asymmetry for localising stimuli. This age-related increase of localisation errors was stronger for the RE than for the LE (Fig. 3A). According to the hemi-aging theory (Lapidot, 1983) and right-hemisphere dysfunction hypothesis (Goldstein & Shelly, 1981), that propose that functions of the right hemisphere decline faster with age than the left hemisphere functions, it would be expected that the elderly would show increased localisation errors for the LE or at least reduced difference in localisation errors between both ears. However, we found increased localisation errors for the RE, which is more in line with the corpus callosum deficit theory (Goldstein & Braun, 1974). Decrease of corpus callosum functioning in elderly would cause less efficient transmission of the information from the RE to the right hemisphere that would be predominantly involved in localising auditory stimuli, resulting in increased localisation errors for the RE. This interpretation is in agreement with findings of reduced corpus callosum size (Doraiswamy et al., 1991; Sullivan et al., 2001; Weis et al., 1991) and reduced callosal functioning in ageing. Several studies using diffusion MRI confirmed disruption of white matter tract and commissural connectivity in normal ageing (Abe et al., 2002; Nusbaum, Tang, Buchsbaum, Wei, & Atlas, 2001; Pfefferbaum et al., 2000; Sullivan et al., 2001) which might lead to reduced callosal function and interhemispheric communication. Age-related increased asymmetry is also suggested in studies involving other modalities like visual and motor modalities that found increased interhemispheric transfer time with increasing age (Bellis & Wilber, 2001; Jeeves & Moes, 1996; Reuter-Lorenz & Stanczak, 2000).

CONCLUSION

Taken together, our results on increased ear asymmetry in dichotic listening performance as a function of age in the focussed attention condition, but not in free attention condition suggests that intentional processes in the frontal areas might be declined in elderly. The finding that age-effects are strongest for the digits presented at the first position and for the unattended ear underscores this idea. Increased recall of digits presented to the RE indicates predominant involvement of the left hemisphere in processing the identity of dichotic digits, while increased localisation errors for the unattended RE might indicate predominant involvement of the right hemisphere in localising dichotic digits. Age-related increased asymmetries for identifying and localising verbal stimuli are in opposite directions and show stronger effects on the ear ipsilateral to the hemisphere which is dominant to that particular function. This indicates that age-related increased asymmetry is due to decline of corpus callosum functioning resulting in reduced interhemispheric interaction rather than by a selective decline of right hemisphere functions.

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